

# Thermal Testing & Integration: Magnetospheric MultiScale (MMS) Observatories with Digital 1-wire Sensors

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## Abstract

Thermocouples require two thin wires to be routed out of the spacecraft to connect to the ground support equipment used to monitor and record the temperature data. This large number of wires that exit the observatory complicates integration and creates an undesirable heat path during testing. These wires exiting the spacecraft need to be characterized as a thermal short that will not exist during flight. To minimize complexity and reduce thermal variables from these ground support equipment (GSE) wires, MMS pursued a hybrid path for temperature monitoring, utilizing thermocouples and digital 1-wire temperature sensors. Digital 1-wire sensors can greatly reduce harness mass, length and complexity as they can be spliced together. For MMS, 350 digital 1-wire sensors were installed on the spacecraft with only 18 wires exiting as opposed to a potential 700 thermocouple wires. Digital 1-wire sensors had not been used in such a large scale at NASA/GSFC prior to the MMS mission. During the MMS thermal vacuum testing a lessons learned matrix was formulated that will assist future integration of 1-wires into thermal testing and one day into flight.

## Nomenclature

<i>MMS</i>	=	Magnetospheric MultiScale
<i>GSE</i>	=	Ground Support Equipment
<i>GSFC</i>	=	Goddard Spaceflight Center
<i>TVAC</i>	=	Thermal Vacuum Chamber
<i>PRT</i>	=	Platinum Resistance Thermometer
<i>LN2</i>	=	Liquid Nitrogen

## I. Introduction

THE Magnetospheric MultiScale mission is built by the NASA Goddard Space Flight Center and encompasses four identically instrumented spacecraft that will use Earth's magnetosphere as a laboratory. These 4 spacecraft each have over 25 instruments that require unique thermal control environments. The orbits in which these spacecraft fly will create an umbra up to 3.85 hours in duration which limits the power accessible by the thermal control system. Thus, a mostly passive system of design has been pursued for the project. This power limitation and the difference between required operating & survival temperatures for each component and instrument required a great understanding of the thermal predictions to keep heater power within reason. To that end a detailed thermal model was necessary and needed to be verified with TVAC testing. To correlate the thermal model in such detail, hundreds of thermal sensors were required for testing. The thermal team for MMS decided to pursue an

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instrumentation methodology for TVAC testing that differed from tests in the past by utilizing 1-wire digital sensors along with thermistors.

## II. What is a 1-wire Sensor

1-wire refers to the technology being used, not the physical number of wires the sensors possess. The basis of the technology is a serial protocol using a single data line plus ground for communication. A 1-wire master device can control and communicate with numerous slave 1-wire devices via a 1-wire bus. Each slave device has a unique 64 bit ID number that serves as the slave address. The slaves draw their power via the bus and usually operate over a range of 3.0 to 5.5 V. 1-wire devices are designed with contact applications in mind.

For the purpose of thermal testing DS18B20 sensors were used on the MMS mission. Each sensor has an operating range of  $-55^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$  and is accurate to within  $\pm 0.5^{\circ}\text{C}$  over the range of  $-10^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$ . The sensors used on MMS came in the configuration as seen in Figure 1 where 1 is the ground (GND) 2, is (DQ) is the data input/output and provides power for parasitic power mode, 3 (Vdd) must be grounded for parasitic power mode. The 1-wire technology allows for easy use with a laptop computer as the computer itself will supply power to the 1-wire bus. The sensor head is TO-92 plastic packaged with an interface surface of approximately 5mm x 5mm.<sup>1</sup>



Figure 1: DS18B20 1-wire Sensor Dimensions

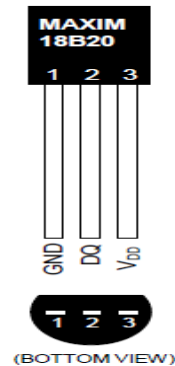


Figure 2: DS18B20  
1-wire Sensor Wire Leads

## III. 1-wire Sensor Plan for MMS

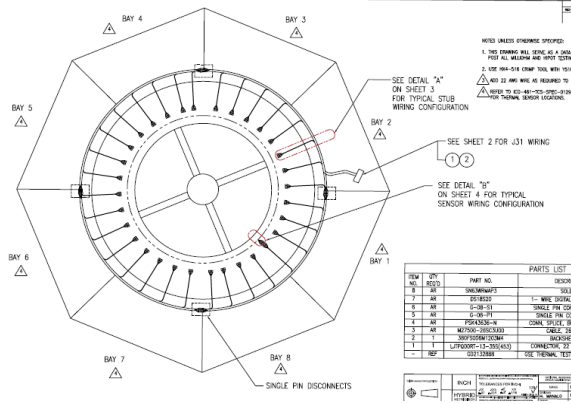
The MMS thermal design relies heavily on passive thermal control techniques. Therefore, it is essential to make sure assumptions on conductivities, optical properties and overall heat flows are in line with model predictions in order to ensure a reliable thermal model of the spacecraft. The significant number of instruments and components on the spacecraft required the usage of over 350 thermal sensors per spacecraft. Due to the intensive process of building 4 large spacecraft at once, a decision was made early on to simplify the integration process where possible. The flexibility the 1-wires afford was seen as a prudent way to speed up thermal subsystem integration and improve reliability.

Along with the 1-wire sensors, a series of other thermal sensors were used for MMS. There are over 75 thermistors and PRT's that are used during flight, but model correlation requires more information than can be provided by these flight sensors. Typically, in the past thermocouples would be installed to supplement the thermistors in TVAC. Thermocouples were used as backups to 1-wire sensors in sensitive locations and where a GSE heater was controlled.

1-wire sensors have a few advantages versus thermocouples that led to the MMS thermal team's decision to utilize them. 1-wires can be spliced and daisy changed together via a bus, reducing significantly the number of wires exiting the spacecraft and thus reducing non flight heat leaks. 350 thermocouples would require 700 wires to be routed out of the spacecraft. MMS had the capability of routing 64 1-wire sensors to a single 3 lead 1-wire bus that exited 3 wires from the spacecraft. MMS grouped 6 such buses together to reduce exit wires down to 18 from a potential 700. Prior spacecraft integration experience provided insight into the fragile nature of thermocouple sensors, as some had been broken or damaged during installation. 1-wires feature a more robust design that significantly reduced the number of repairs needed during integration.

## IV. Integration of 1-Wires

Specific to MMS, the 1-Wire harness was broken up into groups of 64 sensors, called chains. In regards to the implementation of the 1-Wire harness the MMS thermal team broke down each MMS spacecraft into three subsystems, Instrument, Spacecraft, and Propulsion. Two 64-sensor chains span each of these three subsystems, due to barrel splicing hardware constraints each of these chains was further broken down into branches off the main chain. Figure 3 shows one of the decks of the MMS spacecraft with 2 1-wire buses running in a racetrack

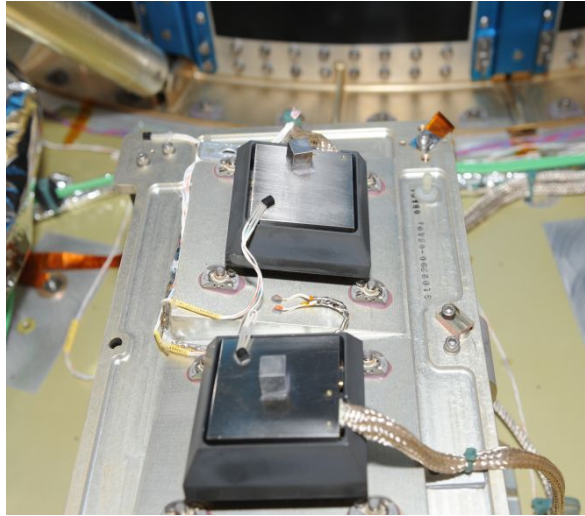


**Figure 3: MMS Spacecraft Deck with 2 1-wire buses**

formulation and the branches off of those buses. This harness design allows for quick and easy manipulation of the 1-Wire harness if a situation were to arise where a sensor needs to be added or removed. Thermistors and thermocouples require a more extensive and less dynamic installation procedure. In cases where sensors had to be easily removed and reattached, as was the case of the MMS Solar arrays, a pin and socket design was used to allow for detachability without compromising the functionality of the harness. Overall, 1-wire sensors had to be installed to fight specifications, as they would be flying integrated with all four observatories. However, since they were not being used to read temperature during flight operations, the 1-wire port had a grounding plug installed before launch.

Prior to bonding and staking of the 1-Wire Harness, a geometrical routing of the harness was designed on the computer and then taped into place on the MMS spacecraft decks using 1" strips of kapton tape that were "tabbed" for easy removal after epoxies had cured, usually about 24-36 hours after initial bonding occurs. 1-Wire sensors require a thermally conductive bonding medium for adhesion to the working surfaces of components. MMS used a combination of Stycast 2850 and Hysol 9394, based on availability of the epoxies to the project. Arathane 5753 with 14% cab-o-sil was used to stake down the harness length along the spacecraft and instrument decks and the propulsion mechanical structures. Hardware prep for 1-Wire sensor bonding included a thorough cleaning of the surface with IPA (Isopropyl Alcohol) wipes to ensure no debris was present that could potentially compromise the bonding of the sensor. The MMS Solar Arrays were a special case where the substrate was a composite which required a roughing of the surface with sandpaper to ensure a good adhesion. A clean room vacuum was set up during sanding operations to reduce particulate generated from this activity. Once complete a thorough cleaning with an IPA wipe is performed.

As previously stated one major advantage of 1-Wire use is the ability to splice multiple sensors together to reduce harness mass and footprint on the spacecraft. Barrel splices are used for permanent connections along the harness, while a pin and socket set up is used for removable sensor splicing. Having the luxury of such a dynamic set lends nicely to a situation where troubleshooting is required. If, for instance, a sensor head has been deemed unusable, a new sensor head can easily be replaced on the same string of harness.



**Figure 4: 1-wire Sensor Bonded to Camera Head**

## **V. Testing of 1-Wires**

During the MMS project 1-wires were fleshed out during numerous test. The thermal team performed two separate tests of the propulsion subsystem where 1-wires were used in conjunction of thermocouples to verify model predictions. Each electronics box underwent thermal cycling and balance with the use of thermistors and 1-wire sensors. Spacecraft wide TVAC testing was performed on all 4 observatories utilizing 1-wires. Localized tests in ambient temperatures were performed on numerous boxes as these components were installed, uninstalled and then reinstalled again multiple times. During these tests the MMS thermal team used LN2 spray canisters to force mechanical thermostats closed in order to view a heater current draw on the component. 1-Wires were used in this case as a temporary sensor to make sure limits of components were not violated with the cold temperatures of the LN2 spray. In short, plenty of testing was performed with the 1-wires to flesh out their advantages and disadvantages.

## **VI. Advantages of 1-wire Sensors**

Conventional methods of monitoring test and on-orbit data include a combination of thermocouple and thermistor telemetry filtering in to a workstation. Major pitfalls to this convention exist due to constraints of the number of sensors a system will allow based on a variety of different constraints. Both thermocouples and thermistors require an individual harness for each sensor located on a system. Thermocouples in particular pose a problem during test scenarios where each sensor harness must exit the spacecraft, which can be difficult when trying to read internal temperature data, and connected to a breakout box interface which can be a tedious and time-consuming activity. 1-Wire capabilities allow for a changing of the guard on how test and flight data is cultivated and utilized. Since 1-Wire sensors harbor the ability to be spliced or daisy chained into a single harness, a limitless number of sensors can be placed on the given working platform to capture all of the data one could ever possibly desire. The more information that can be derived from a test/flight situation will lead to a better understanding of the fundamentals of the thermal performance of a given system which in turn results in a more efficient and detailed model that will aid in forecasting future scenarios that a system may face.

### **A. Harnessing**

With a spacecraft as large and as complex as MMS integration was an intensive process with numerous hands on the spacecraft and all times. It was seen on numerous occasions that thermocouples would be pulled from their initial location or accidentally cut or broken. Thermocouple wires are thin, break easily and they were everywhere because they all had to be routed to one exit location. When a thermocouple broke it was difficult to assess where the problem was. 1-wires were more robust and less intrusive. If a wire was damaged it was easy to find the sensor and the source of the issue as it had less harness to investigate.

## **B. Flexibility**

The 1-wire sensor was a very flexible system. If we learned that we needed to add sensors to a new location late in integration all we had to do is bond the sensor and splice into a nearby harness. With thermocouples, if a section of the spacecraft is inaccessible late in integration adding the sensor can be difficult. Being able to read the 1-wire bus via a USB into any laptop is very convenient during smaller tests and during installation checkout procedures

## **VII. Disadvantages of 1-wire Sensors**

Using 1-wires on a large scale is a relatively new concept for NASA/GSFC, in turn there were some issues that needed to be resolved. During the integration and test campaign there were situations where it became evident that in some cases more care was needed when working with the 1-wire sensors.

### **C. Sensor Shorting**

The 1-wires connect to a bus similar to a Christmas tree light strand. If sensors are not spliced together completely they can fail other sensors. It was learned that after each new branch of sensors was added to any bus that they must be thoroughly vetted through checkout software. Since there are three wires needing to be spliced to the bus in proper configuration, there can be instances where they are switched which can kill the entire 1-wire bus.

### **D. Single Point Failures**

Just prior to an observatory TVAC test it was learned that a branch of 64 1-wire sensors had failed. A sensor was not properly checked out prior to insertion into the TVAC chamber and it was improperly installed shorting the entire chain. One bad sensor killed 63 other sensors. Proper checks and balances can alleviate this concern, however it is something to be cognizant of.

### **E. Temperature Induced Failures**

The operating range of the sensors is down to -55 °C. We installed sensors on the Solar arrays which dropped to -150 °C during TVAC chamber, well outside the operating limits of the sensors. It was learned that when the sensors dropped below -70 °C, that the entire chain went out for that duration, not just the sensors attached to the solar array. So in areas susceptible to exceeding limits of the sensors thermocouples may be necessary.

### **F. Trouble Shooting 1-Wire Issues**

As with other spacecraft components potential issues present themselves over the course of working day to day with said system, 1-wires are no exception. In order to alleviate risk while installing 1-wire sensors the thermal engineer should have the 1-wire software running continuously while work is being done on the spacecraft sensors. Having the 1-wire software running during installation of the sensors will allow the installer to see at what point the 1-wire string went down if there is a failure. This streamlines the troubleshooting process as early on when working with the sensors the MMS thermal team would check out the sensors after an entire string had been installed. This means that if there was a failure, each sensor would have to be carefully inspected to see where a mistake had been made, being that there could be up to 64 sensors on a string this can be a time consuming process.

## **VIII. Lessons Learned**

Utilizing 1-wire sensors simplified many processes for the thermal team and easily provided robust data. However, there are lessons learned that if carried over to future projects will make the usage of 1-wire sensors even better. Early on in the design process using 1-wires should be decided upon. Each subsystem of the spacecraft should be made aware of the decision and have inputs in the routing and execution of using the 1-wire buses. Had MMS had a little more cooperation with the electrical harness team the 1-wire bus could have had a seamless integration into the harness as opposed to being laid on top as an afterthought during MMS. This could reduce stresses between the thermal team and electrical team during integration as the harness is accessed frequently. The routing of the 1-wire buses and branches could have been better laid out with assistance from the other subsystems.

Aside from harness routing the physical integration of sensors to the bus is an area where careful attention needs to be paid. Shorting a sensor or incorrectly connecting one of the 3 wires of a sensor can kill the functionality of the

entire bus. During integration an engineer should check the viability of the sensor and the bus after every new sensor is added. This can simply be done by hooking up a USB to the end of 1-wire bus to a laptop computer.

Make plans early in the project to make sure the software capabilities for the 1-wires are up to your standards. The software had limited plotting capabilities which could have been upgraded via software scripts.

Just as with thermocouple wires thermal shorts can arise if the 1-wire harness is not properly routed. During testing of ultra isolative thermal standoffs for the prop system tests, it was learned improperly routed 1 wires almost doubled up the expected conductivity of the standoffs. This is more of a concern for 1-wires versus thermocouples, as near the sensors there are 3 wires versus 2. 1-wires also use a thicker gauge of wire, which can cause a larger heat leak due to the added thermal mass.

## **IX. Conclusion**

Thermal was incredibly impressed with the 1-wire capabilities and how they helped out during TVAC. As with any hardware integrated to a spacecraft, careful planning is a must in order to maximize effectiveness. Careful planning of the 1 wire harness routing in conjunction with other subsystems is of utmost importance as to being able to successfully coexist with these other systems. It is essential to be attentive to the sensor integration procedure to the 1-wire bus to avoid shorts. With this knowledge in hand, and effective testing routines performed on hundreds of 1-wire sensors it is hoped that GSFC will start integrating 1-wires with some flight capabilities in mind. The flexibility and dynamic nature of these sensors should pave the way for 1-wires to be the next major enhancement in how temperature is read and transmitted during flight operations.

## **REFERENCES**

<sup>1</sup> Site <http://www.maximintegrated.com/en/app-notes/index.mvp/id/1796> for 1-wire description